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TITLE: ULTRA-HIGH DENSITY PLASMA EXPERIMENTS: MHD SIMULATIONS

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ABSTRACT

High density, laser-initiated, gas-embedded Z-pinch experiments which are being performed at Los Alamos are being treated computationally using a two-dimensional magnetohydrodynamic computer code. All aspects of the experiment are modeled including the laser-optics system, the Marx-bank/transmission line, electron avalanching, and the experimental diagnostics. Experimental observations have been reproduced very well. The plasma produced in the experiments has $n_e > 10^{20}/cm^3$, T=200eV, and $n_e\tau > 2x10^{13}$ s/cm^3.

Advances in pulsed power technology have made it possible to build a new type of plasma device, a laser-initiated, gas-embedded Z-pinch in which the plasma is primarily ohmically heated[1]. A device characterized by an energy of 70kJ and a peak charge voltage of 600kV has produced a plasma with $n_e > 2x10^{20}/cm^3$, T=200eV and $n_e\tau > 2x10^{13}$ s/cm^3; two-dimensional magnetohydrodynamic(MHD) computer calculations have reproduced the experimental observations to a very satisfactory degree[2]. In this paper we describe our computational model, computed results, and predictions.

Our computations model all aspects of the experiment. A voltage is applied across the electrode gap, an initiating laser is discharged along the axis, and current flows between the electrodes to create a hot, dense plasma column. In the computations a laser-optics package computes the temporal and spatial evolution of the laser profile in the discharge chamber. A Marx-bank/transmission-line package computes the temporal evolution of the self-consistent voltage across the discharge chamber. An electron avalanche model uses a non-linear Ohm's law to compute the spatially and temporally dependent electric field and the resulting non-uniform increase in electron density. When current flows, two-dimensional MHD calculations determine the spatial and temporal evolution of the plasma density, plasma temperature, plasma velocity, and magnetic field profiles. The MHD model includes thermal conduction, resistive diffusion, radiation, dissociation, and ionization in addition to the Lorentz $\underline{J}\times\underline{B}$ force in a fluid description of the plasma. The charged-particle transport coefficients are "classical" and the atomic processes are based on local thermodynamic equilibrium(LTE). An extensive post-processor computes spectra from infra-red to x-ray frequencies, temperatures based on x-ray absorption by two different thicknesses of aluminum foil, and Schlieren shadowgrams, all of which can be compared directly to experimental data.

The plasma is formed in a chamber containing 3atm of H_2 between electrodes spaced 10cm apart. A current channel is formed from the pulse of a 5 J neodymium-glass laser which is focussed along the symmetry axis and which is fired near the peak of the voltage across the electrodes($\approx$400kV). The current rises to 250kA in 200ns.

According to our computations the laser initiation is very non-uniform and hence the initiation process is a complex two-dimensional one involving virtual electrode formation and streamer propagation. However, our two-dimensional calculations indicate that the plasma column is remarkably one-dimensional for greater than 75ns. Typical radial profiles are shown in Fig. 1; the mass density profile shows a shock wave propagating into the neutral embedding gas. Later in time an m=0 instability occurs in the computations when the central column expansion is stopped by the magnetic force. Even after the occurrence of the m=0 instability the computations reproduce the experimentally observed Schlieren shadowgrams(Fig. 2), "two-foil x-ray" temperatures(Fig. 3), and visible light measurements where the computed non-uniform source rate and corresponding plasma reabsorption are taken into account(Fig. 4). The computed shadowgram diameter of Fig. 2 corresponds to the front of the outward moving shock wave shown in Fig. 1; the actual current carrying channel is significantly smaller in diameter than the shadowgram and has a diameter of less than 1.5mm at 200ns. After an initial rapid rise the temperature reaches a plateau (Fig. 3) even though the current continues to rise.

According to the computations this is due to mass accretion into the column from the embedding gas, a two-dimensional effect caused by enhanced coupling of energy from the hot core to the outside as a result of the m=0 instability and by continued electron avalanching in the embedding gas.

Our MHD code has been used to scope out other possible modes of operation. These modes include operating at higher voltages, reducing and increasing the fill pressure, and using narrower, more intense laser beams. Our computations predict that higher fill pressures or narrower laser beams can lead to significantly higher temperatures although the m=0 instability may limit performance.

Our computations have been useful in the interpretation of experimental data and in the prediction of new experiments and the computed results appear to verify our initiation and MHD models. Questions remain to be answered on the nature of the instabilities and their effect on limiting the ultimate plasma temperature.

References

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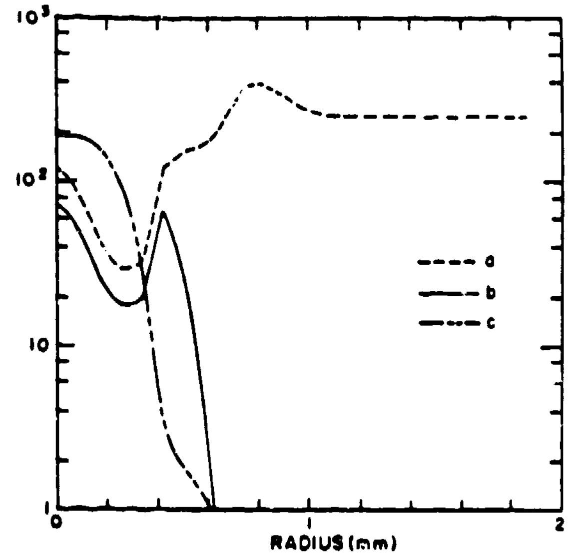

Fig. 1

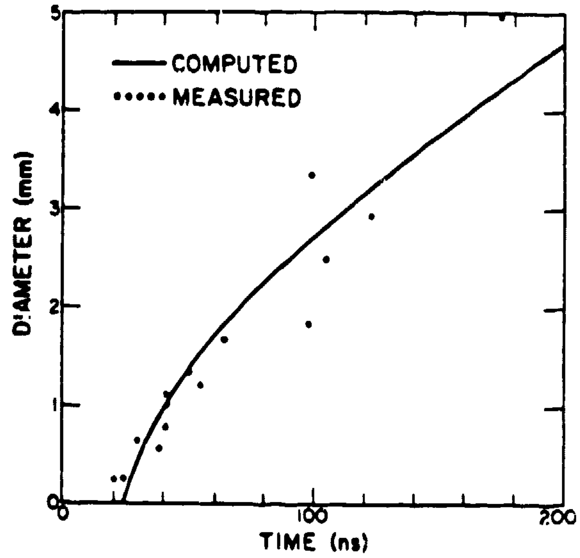

Fig. 2

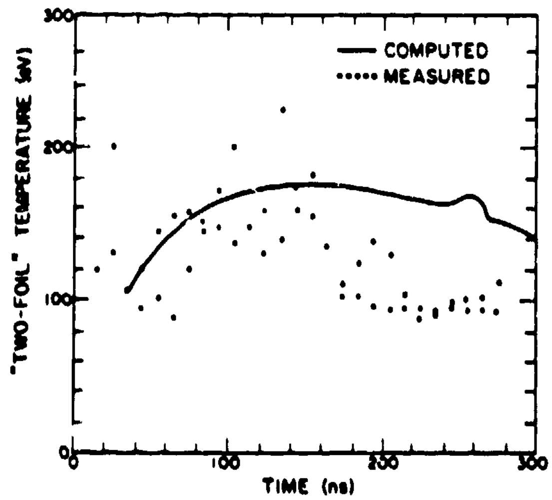

Fig. 3

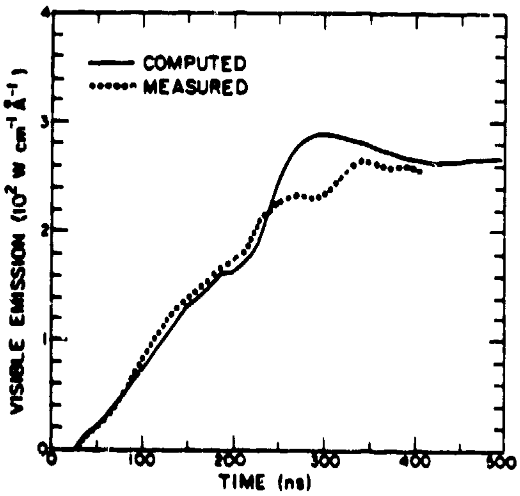

Fig. 4

Fig. 1. Typical Radial Profiles at 75ns: (a) Mass Density-10^{-3}kg/m^3; (b) Electron Number Density-10^{18}/cm^3; (c) Temperature-eV.

Fig. 2. Computed and Measured Schlieren Shadowgram Diameter.

Fig. 3. Computed and Measured "Two-Foil x-ray" Temperature.

Fig. 4. Computed and Measured Visible Emission at 4000 angstroms.